Investigation of the Effects of Evaporation and Infiltration on Vadose Zone Pore-Fluid $\delta^{18}O$ Values at Hanford, Using ToughReact

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RESEARCH OBJECTIVES

The fraction of rainfall that percolates deep into the vadose zone in arid regions is difficult to predict, but important for understanding groundwater recharge and contaminant transport. At Hanford, where a large amount of radionuclide contamination is present in the vadose zone above the water table, it is especially important to know the water infiltration flux, because this determines how rapidly radionuclides will reach groundwater. This study is aimed at evaluating the use of numerical models in conjunction with water isotope data to measure infiltration flux in arid regions.

APPROACH

The vadose zone hydrological processes that control infiltration also generate variations in the ratios of stable isotopes (i.e., $^{18}O/^{16}O$ and $^{2}H/^{1}H$) in water and water vapor. A numerical modeling approach is needed to account for the interplay between evapotranspiration, advection, and diffusion. We implemented the temperature-dependent equilibration of stable isotopic species between water and water vapor, and their differing diffusive transport properties, into the thermodynamic database of the reactive transport code TOUGHREACT, developed at Berkeley Lab. This allows for the simulation of stable isotope fractionation in tandem with multiphase unsaturated flow, heat transport, mineral-water-gas reactions, and the transport of other gaseous and aqueous species.

ACCOMPLISHMENTS

TOUGHREACT simulations with isotope fractionation provide new insights into the behavior of water isotopes in unsaturated zone pore waters in semi-arid climates. Preliminary results (Figure 1) emphasize the effects of alternating wet and dry seasons, which lead to annual fluctuations in moisture content, capillary pressure, and stable isotope compositions in the vadose zone. The effective depths of evaporation and wetting events are primarily controlled by soil properties and infiltration rate. Repeated annual cycles of wet and dry seasons in a semi-arid climate lead to a consistent shift in the isotopic composition of deep vadose zone pore waters, which is proportional to the amount of infiltration.

SIGNIFICANCE OF FINDINGS

Stable isotope profiles provide a dynamic record of evaporation and infiltration in the unsaturated zone. For the range of infiltration rates measured at the Hanford Site (5–200 mm/yr), stable isotope profiles are affected by surface conditions on annual-to-decadal time scales, and therefore can provide a record of recent events such as dumped or spilled waste water, soil removal, and devegetation by brush fires. Numerical simulations of transport and isotope fractionation using TOUGHREACT provide a method to quantitatively interpret the relationship of stable isotope depth profiles to infiltration rate.

RELATED PUBLICATION

Singleton, M.J., E.L. Sonnenthal, M.E. Conrad, and D.J. DePaolo, Numerical modeling of stable isotope fractionation and multiphase reactive transport of water and water vapor using TOUGHREACT. Proceedings, TOUGH Symposium, Berkeley, California, 2003.

ACKNOWLEDGMENTS

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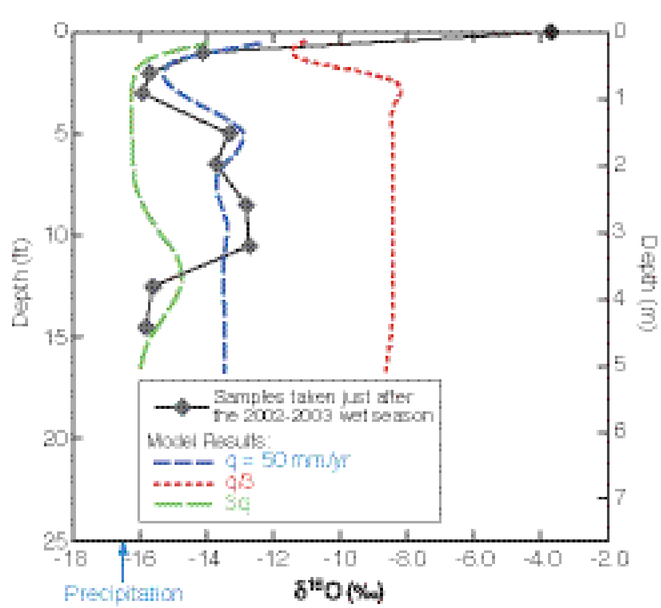

Figure 1. Model results for a vertical Hanford Site vadose zone profile of oxygen isotope compositions with different infiltration rates (q), compared with pore-water samples taken just after the wet season from a lysimeter where the infiltration rate is known to be 55 mm/year